ANALYSIS OF ENERGY CONSUMPTION OF DUPLEX RESIDENCES IN COLLEGE STATION, TEXAS

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ABSTRACT

This paper characterizes the variability of energy consumption due to a series of construction, occupant, and weather-related effects in duplex residences in College Station, Texas. In this paper, spline regression was used to estimate cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature for monthly billed kWh against average daily outside temperature. These estimates were used to predict normalized annual consumption. Best subsets regression and multiple regression were used to explore the relationship between energy consumption and construction, occupant, and weather-related factors.

The sample for this paper was 140 duplex residences which used only electricity for cooling and heating, and had one year minimum occupancy in College Station, Texas. The spline regression models with weather-related factors achieved adjusted R^2 values averaging 0.82. Construction, occupant, and weather-related factors were determined to be components of energy consumption. In the final modeling, construction, occupant, and weather-related factors accounted for 93% of the variance for the normalized annual consumption of duplex residences.

The findings showed there was a significant relationship between normalized annual consumption and year built, thermostat setting, cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature.

INTRODUCTION

The United States, with only 4.6% of the world's population, uses about 20% of the world's energy and resources (Hinrichs, 1996). Not only does the nation consume a large share of the world energy supply, but the rate of energy consumption has been increasing rapidly during this century. Of the total energy used in the country, all buildings account for 37% of the energy use and residential buildings account for approximately 20% (Lechner, 1991). Therefore, energy conservation is a necessary inquiry in architecture.

An energy analysis simulation program approach, such as DOE-2 (LBL, 1993), is often used to estimate the total energy used in a building and to estimate how much the construction components that influence the building's energy consumption. However, because the actual building operations are often different, engineering-type energy simulation tools alone are not able to determine the actual building's energy use (Burt Hill Kosar Rittelmann Associate, 1987). Statistical analysis is another approach that can be introduced to model energy consumption for buildings. Inverse modeling techniques have been used to estimate the performance of an existing building under future weather and occupancy conditions (ASHRAE, 1997). In this model approach, a structure or physical configuration of the building or system is assumed first and then important factors are identified by a statistical analysis (Rabl & Riahle, 1992). Because statistical analysis actually utilizes real measurements on study variables, there is no estimation necessary for these variables (Woods, 1982). The base load calculation in an engineering calculation assumes operating hours per month for the lights, range and other equipment. A statistical approach simply measures the actual energy consumption during periods when neither cooling nor heating occur, it does not require estimation of hours of equipment use.

The total number of residential buildings in College Station increased by 18.6% from 1990 to 1995 (Hankins, 1997). However, residential energy consumption increased 23.4% during the same time period (Roman, 1996). During the last decade statistical analysis has been used to analyze energy performance in buildings. Most research (Gladhart, 1983; Larson, 1994; Ellingson, 1997) using statistical analysis has concentrated on detached, single-family houses and mobile homes. This study will attempt to expand this type of inquiry to duplex housing. Because of common walls, energy performance for duplex housing may differ from detached, single-family houses, and this study may quantify differences. This study is further warranted because an effective model for buildings can aid in predicting energy consumption. Many factors impact building energy performance, whether independently or interactively. Exploration of the relationships among construction, occupant, and weather factors should add to the understanding of energy consumption.

RESEARCH OBJECTIVES

The objective of this study was to characterize the variability of energy consumption statistically due to three types of factors that effect energy consumption in duplex residences in College Station, Texas.

Normalized annual consumption for each duplex residence was used as dependent variable. Three types of independent variables were considered. They were construction, occupant, and weather-related factors. Construction-related factors included market value, floor area, perimeter, length of common wall, year built, wall materials, roof reflectivity, shading factor, orientation perpendicular to the common wall, and number of bedrooms. There were seven occupant-related factors: winter thermostat-set temperature, summer thermostat-set temperature, programmable thermostat setting, adjusted thermostat setting, number of occupants, student or not, and monthly rent. Weather-related factors included cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature.

The general objectives of the study were to examine the effects of construction, occupant, and weather-related factors on normalized annual consumption.

METHODS

Data

The target population of this study was duplex housing in College Station, Texas. 1149 duplex housing units which use only electricity for cooling and heating were identified by field surveys in January, 1997. Using sample size tables (Cohen, 1988), an adequate sample size for this study was estimated at 139 duplex housing units. Units with vacancies were excluded, and 140 duplex housing units were chosen on the base of single occupant of one year.

Utility billing data were acquired from the City of College Station. Utility billing data were discarded if they were not 12 consecutive months of utility data with one set of occupants for the study period.

College Station retains utility billing data for twenty-four months, so data from thirteen (minimum) to twenty-three months (maximum) of utility billing data could be obtained for each residence.

Daily maximum and minimum weather data were obtained from the State Climatologist Office at Texas A&M University. Maximum and minimum outdoor dry-bulb temperatures were collected for the study period as well as long-term monthly average for a twenty five-year period (1971 - 1996). These long-term averages were used to calculate normalized annual consumption.

Weather-related factors, such as cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature were calculated using COMBEAS (Woods, 1993) and the following procedures.

1. Average: This procedure calculated the number of days in each consumption period and average periodic temperature. A plot of the energy consumption vs. the billing period mean outdoor temperature produced a pattern of energy consumption for each duplex residence, and from this plot, modified cooling and heating balance temperatures were estimated visually.
2. Initial regression: A spline regression process began with the estimate of the balance temperatures. Using the heating and cooling model shown in equation 1, a spline regression procedure was done using the estimated balance temperatures as the points at which the segmented lines met, modified cooling balance point temperature (T_c) and modified heating balance point temperature (T_h). This first spline regression, in turn, provided an estimate of the intercept, base load (β_0) and an estimate of the cooling and heating efficiencies, β_1 and β_2.

$$kWh/day = \beta_0 + \beta_1 * \max(T_{avg} - T_c, 0) + \beta_2 * \min(0, T_{avg} - T_h) + \varepsilon \quad (1)$$

where kWh/day = estimated electrical energy used per day, β_0 = base load, β_1 = cooling efficiency, β_2 = heating efficiency, T_{avg} = average billing period temperature, T_c = modified cooling balance point temperature, T_h = modified heating balance point temperature.

3. Iteration: The iteration process calculated exact modified cooling balance point temperature, modified heating balance point temperature, cooling efficiency, heating efficiency, and base load.

4. Second regression: Another spline regression, using the equation 1, was run using the exact balance temperatures found by previous procedure. The regression listed, and the plot of the predicted billing period kWh usage versus the average outside temperature established several measures of efficiency. Those measures were the modified cooling balance point temperature, modified heating balance point temperature, cooling efficiency, heating efficiency, and base load.

Normalized Annual Consumption (NAC) (Fels, 1986), as a dependent variable, was calculated by substituting the normalized average temperature for each month into equation 1 given previously. This yields normalized daily consumption for each month.

Construction-related factors, such as market value, floor area, perimeter, length of common wall, wall materials, and year built were examined at the Brazos County Appraisal District. Market value indicates total value which includes land and improvement value. Floor area is the conditioned floor area, and perimeter is the outside perimeter in linear feet of the conditioned floor area. Wall materials also were identified. Roof reflectivity and orientation perpendicular common wall were measured with a luminance meter and compass. Equation 2 shows the formula generally used to calculate the roof reflectivity. Roof surface brightnesses were measured with a spot brightness meter that measured in foot lamberts (FL). The method used was to compare the roof surfaces to a calibrated white board with a measured reflectance of 0.9. The relationship was as follows:

$$\rho_{roof} / \rho_{white\ board} = FL_{roof} / FL_{white\ board}$$

$$\rho_{white\ board} = 0.9$$

$$\rho_{roof} / 0.9 = FL_{roof} / FL_{white\ board}$$

$$\textit{Roof reflectivity}\ (\rho_{roof}) = (FL_{roof} / Fl_{white\ board}) * 0.9 \quad (2)$$

Orientation perpendicular common wall is recorded in eight categories (see Figure 1). Shading factors were determined by a visual observation method (see Figure 2) (Degelman, 1996).

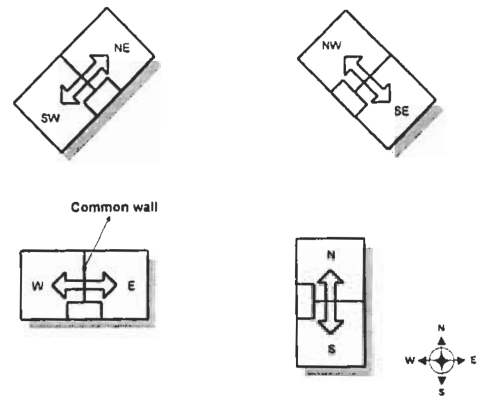

Figure 1. Orientation perpendicular to the common wall.

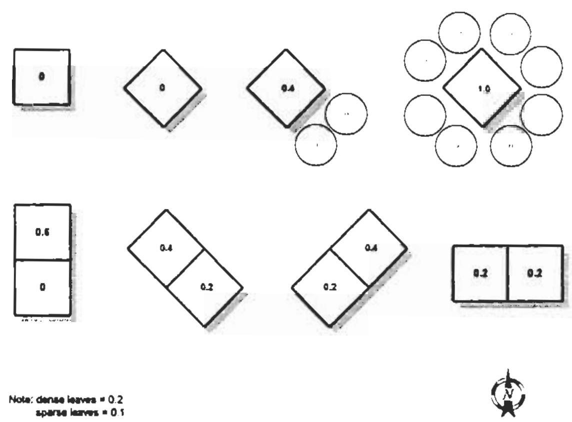

Figure 2. Shading factors

Information for occupant-related factors, such as thermostat-set temperature, student or not, monthly rent, number of occupants, and household energy consumption practices were gained from telephone surveys. Household energy consumption practices included data for programmable thermostat setting and adjusted thermostat setting. Much of the data regarding occupant behaviors performed were acquired by self-reported. A telephone survey was conducted in February 1997.

Parameter estimates

The patterns of energy consumption for each of the 140 duplex residences remaining in the sample were determined by spline regressions run to evaluate the relationship of energy consumption versus outdoor temperature. The patterns were defined by parameter estimates which provide the best source of the values of cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature. The parameter estimates of the values which described the pattern of electrical consumption varied from duplex residence to duplex residence.

Duplex residence number 24 was used as an example through the COMBEAS analysis. As a first step (Average program) in the analysis, a scatterplot (see Figure 3) was made showing kWh consumption per day versus mean outdoor temperature for a billing period. After examing this scatterplot, the researcher made a visual estimation of the location of the heating and cooling balance point temperatures. In this case, lines were drawn in the figure to show

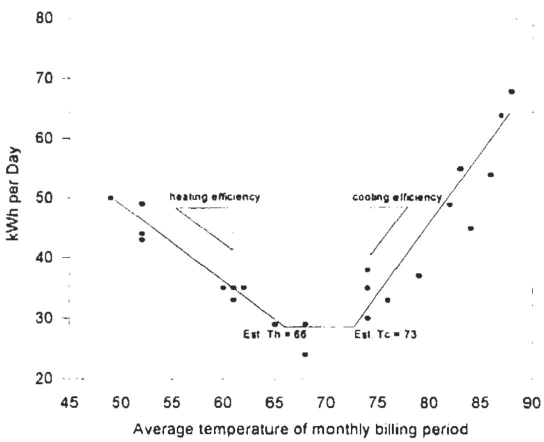

Figure 3. Plot of energy consumption vs. temperature (Average program) - Duplex residence # 24.

the process and the initial estimated balance point temperatures. The estimated heating balance point temperature is 66° F and the estimated cooling balance point temperature is 73° F. As a second step (Initial regression), the first time through the regression process, the estimated balance point temperatures, T_h and T_c, were used in the model as shown in equation 1. The analysis of variance from this first regression process provided the parameter estimates used as input to the non-linear regression process. The analysis of variance for the spline regression which uses the estimated balance temperatures is shown in Table 1. This ANOVA table includes the cooling efficiency, heating efficiency, and base load. As a third step (Iteration program), the non-linear regression process was used to provide more exact parameter estimates for balance point temperatures.

The non-linear regression process eliminates the necessity for several regressions, each with a change in the values of the balance point temperatures to get the optimum R^2 value. Table 2 shows one example of the least squares summary statistics from the non-linear regressions run on the energy consumption data of duplex residence number 24. As a fourth step (Second regression), final spline regressions were run to establish the significance of relationship between mean outdoor temperature and the kWh electrical consumption. Table 3 shows example of the analysis of variance from the final spline regressions.

Table 1. ANOVA table from a spline regression (Initial regression) - Duplex residence # 24.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2699.01259	1349.50629	94.570	0.0001
Error	20	285.39829	14.26991		
C Total	22	2984.41088			

Root MSE	3.77755	R-square	0.9044
Dep Mean	42.09436	Adj R-sq	0.8948
C.V.	8.97401		

Parameter Estimates

Variable	DF	Estimate	Parameter Error	Standard Parameter=0	T for H0: Prob > |T|
INTERCEP	1	28.319718	1.34275999	21.091	0.0001
B1	1	2.240366	0.16338143	13.712	0.0001
B2	1	-1.224532	0.16175008	-7.571	0.0001

Table 2. Non-linear least squares summary statistics (Iteration program) - Duplex residence # 24.

Non-Linear Least Squares Summary Statistics

Source	DF	Sum of Squares	Mean Square
Regression	4	43465.828279	10866.457070
Residual	19	273.095469	14.373446
Uncorrected Total	23	43738.923748	
(Corrected Total)	22	2984.410883	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Lower	Interval Upper
T_COOL	71.57422428	0.0000000000	71.574224276	71.574224276
T_HEAT	67.06536082	2.6096342846	61.603372520	72.527349125
INTERCEP	26.56896552	1.5333201913	23.359712405	29.778218629
B1	2.12800401	0.1763939170	1.758809937	2.497198083
B2	-1.25787143	0.2284038362	-1.735922733	-0.779820118

Table 3. ANOVA table from a spline regression (Second regression) - Duplex residence # 24.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2710.03157	1355.01579	98.770	0.0001
Error	20	274.37931	13.71897		
C Total	22	2984.41088			

Root MSE	3.70391	R-square	0.9081
Dep Mean	42.09436	Adj R-sq	0.8989
C.V.	8.79907		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	26.974537	1.39869755	19.285	0.0001
B1	1	2.169522	0.15458759	14.034	0.0001
B2	1	-1.232974	0.15270138	-8.074	0.0001

Adjusted R^2 value for the duplex residence number 24 is 0.90. This indicates a very good fit. The parameter estimates were all significant. The regression parameter estimates are the heating efficiency, cooling efficiency, and the base load which were to be used in the stepwise regressions. Plot of the predicted values of energy consumption versus outdoor temperature is shown Figure 4.

The mean cooling efficiency of the 140 duplex residences was 1.91 kWh per cooling degree day. The mean heating efficiency was -1.68 kWh per heating degree day. These efficiencies provide an indication of economy of operation. The modified cooling balance temperature and modified heating balance temperature were 72.14 and 63.86° F respectively. The mean base load was 29.80 kWh/day. The mean adjusted R^2 for all 140 spline regressions was 0.82. On average, 82.02 percent of

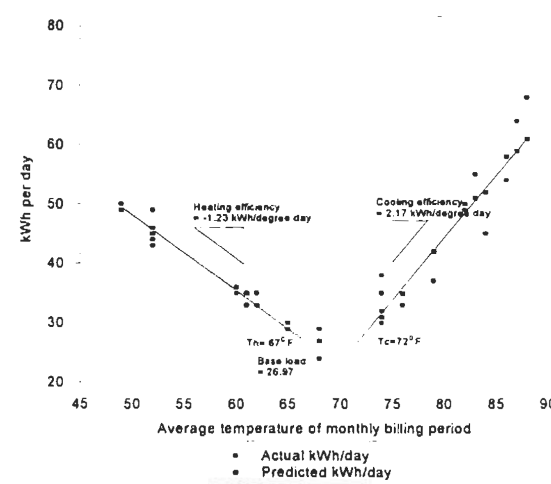

Figure 4. Plot of energy consumption vs. temperature (Second regression) - Duplex residence # 24.

variation of kWh consumption was explained by the individual spline regressions with mean outdoor temperature as the only independent variable in the model. Outdoor temperature only affects the energy consumption of the duplex residence when the mean outdoor temperature for the billing period was below 63.86° F or above 72.14° F. An equation for aggregate energy consumption of 140 duplex residences in College Station is as follows:

$$\text{kWh /day} = 29.8054 + 1.9101 * \max(T_{avg} - 72.14, 0) + 0.6819 * \min(0, T_{avg} - 63.86) \quad (3)$$

Normalized annual consumption

The College Station long-term mean monthly temperatures from 1971 to 1996 are shown in Figure 5. Normalized Annual Consumption (NAC) is calculated using the model parameters and long-term average monthly temperatures. Equations 4 and 5 were used to estimate the kWh for heating and cooling in those months when the mean outdoor temperature for the month was greater than the modified cooling balance point temperature or less than the modified heating balance point temperature:

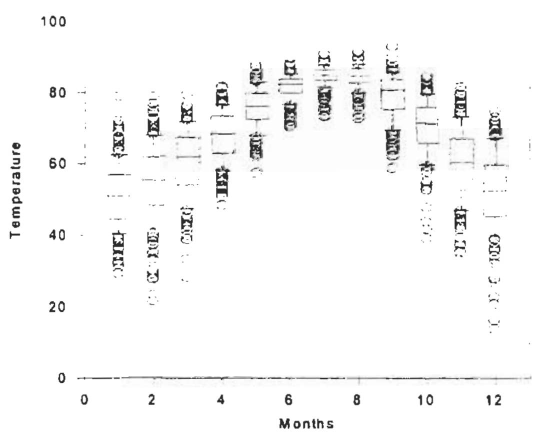

Figure 5. Normalized annual temperatures for College Station.

$$kWh_{cool} = \beta_1 * (T_{avg} - T_c) * \text{Number of Days} \quad (4)$$
$$kWh_{heat} = \beta_2 * (T_h - T_{avg}) * \text{Number of Days} \quad (5)$$

where kWh_{cool} was the kilowatt hours of electricity which were used for space cooling during a normal month, kWh_{heat} was the kilowatt hours of electricity which were used for space heating during a normal month, T_{avg} was the mean outdoor temperature for the month, T_h was the modified heating balance point temperature, T_c was the modified cooling balance point temperature, β_1 was the cooling efficiency from the spline regression, β_2 was the heating efficiency from the spline regression, and 'Number of Days' was the number of days in the month. Equation 6 was used to estimate the base load usage:

$$kWh_{baseload} = \beta_0 * \text{Number of Days} \quad (6)$$

where $kWh_{baseload}$ was base load usage for each month, β_0 was intercept value, and 'Number of Days' was the number of days in each month. Table 4 shows the calculated kWh of consumption over a normalized year for the duplex residence number 24.

The mean annual heating and cooling consumption of the 140 duplex residences were

Table 4. Estimated monthly energy consumption for duplex residence # 24 over a normalized year.

Month	no. of days	normalized temperature	cooling kWh	heating kWh	base load kWh	base load %	cooling month	heating month
January	31	48.5	0	705	836	54	0	1
February	28.25	52.4	0	507	762	60	0	1
March	31	60.3	0	255	836	77	0	1
April	30	68.2	0	0	809	100	0	0
May	31	74.6	175	0	836	83	1	0
June	30	80.7	566	0	809	59	1	0
July	31	83.6	780	0	836	52	1	0
August	31	84	807	0	836	51	1	0
September	30	78.6	430	0	809	65	1	0
October	31	69.4	0	0	836	100	0	0
November	30	59.8	0	266	809	75	0	1
December	31	51.4	0	595	836	58	0	1
Total			2759	2329	9851	78	5	5
Confidence Level (95%)	0.4754	7.3227	183.8646	151.8417	12.8020	9.9047	0.2913	0.2913

2116.18 and 2122.16 kWh respectively. The mean base load was 10886.36 kWh.

Interpretation

Spline regressions were used to estimate cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature for monthly billed kWh and average daily outside temperature. These estimates were used to calculate normalized cooling consumption, heating consumption, and base load in kWh. Individual spline regressions were run for each duplex residence.

Univariate analysis was then used to examine the characteristics of each independent variable and dependent variable. Multivariate analysis was used to explore the relationship between dependent variable and three types of factors. It was employed to analyze the contribution of the independent variables to the variation of the dependent variable. The variables were entered in a model in the sequence obtained through stepwise regression analysis. Best subsets regression, among the stepwise regressions, was used to select variables by systematically searching through the different combinations of the independent variables and selecting the subsets of variables that best contribute to predicting the dependent variable. After selecting the best model from the stepwise regression procedure, the final multiple regression was run for the predicted values of energy consumption. The level of significance of a statistical test is the probability of rejecting the null hypothesis when it is true. The significance level of 0.05 were used for this study. Variance inflation factors were used to detect multicollinearity of independent variables when doing the stepwise procedure. If the variance inflation factor is at or near 1.0, there is no redundant information in the other independent variables. Variance inflation factor values above 4 suggest possible multicollinearity, and values above 10 indicate serious multicollinearity (Fox, Kuo, Tilling, & Ulrich, 1994).

Statistical analyses were accomplished using COMBEAS, SAS for Windows v.6.10 (SAS Institute, 1985), and SigmaStat for Windows v.2.0 (Jandel Corporation, 1995).

RESULTS AND INTERPRETATION

Univariate analysis

The mean market value of the sample duplex residences was $33291. The mean value of the floor area was 932 square feet. The mean perimeter was 94.42 feet. There is a sizable difference of 74.5 feet between the minimum perimeter, 63.5 feet, and the maximum perimeter, 138 feet. The reason why some duplex residences had two stories building which was composed of one unit. The mean and median value for the length of common wall were both 36 feet. The mean year built for the duplex residences was in 1979. The mean roof reflectivity was 0.14. This means that most of the roof colors for sample duplex residences were dark. The mean shading factor was 0.51. This value of the shading factor might be affected by large trees. The mean value for the number of bedrooms of the sample duplex residences was 2 bedrooms. For wall materials, more than 80% of the sample reported having brick, and 15% of the sample reported having wood. For orientation perpendicular to the common wall, more than 62% of the sample reported that they faced NE or SW.

Thermostat-set temperatures, energy consumption practices, number of occupants, student or not, and monthly rent are self-reported. The mean winter thermostat-set temperature was 71.6° F and summer thermostat-set temperature was 73.3° F. There was a sizable difference of 24° - 29° F among the mean thermostat-set temperatures of the 140 duplex residences for summer and winter. These big differences might be the result of the different lifestyle of each duplex resident. The mean value of the number of the occupants in the sample was 2.6. The mean value of the monthly rent of the duplex residences in the sample was $525. 80% of the respondents of duplexes in the sample reported they did not use programmable thermostat setting. 48.6% of the respondents also reported they adjusted their thermostat rarely; 31.4% of the respondents adjusted their thermostat at bed time and when they got up in the morning; 20% of the respondents adjusted their thermostat frequently through the day. 50.7% of the respondents reported that head of their household was student.

The mean daily energy consumption of all duplex residences in the sample was 42.4 kWh /day. In a 30 day month this would amount to 1272.6 kWh. If the cost of electricity was $0.07 per kWh, the average monthly bill would be $89.08/household.

Multivariate analysis

A stepwise regression was first performed using best subsets regression procedure. This was done in order to find the subsets of independent variables that best contribute to predicting the normalized annual consumption. Results of the analysis are shown in Table 5. Based on the results of the analysis, seven variable model which had a R^2 value of 0.93 was produced. The regression equation can be written as follows:

Normalized annual consumption = 195169.95 - 94.47 * year built + 429.86 * adjusted thermostat-set B + 683.23 * cooling efficiency - 500.70 * heating efficiency + 352.40 * base load - 221.64 * modified cooling balance point temperature + 157.94 * modified heating balance point temperature (7)

After selecting the subsets of variables, a multiple regression was performed using the variables which met the significance level of entry at 0.05 selected through best subsets regression procedure. Table 6 shows the analysis of variance from the multiple regression procedure on the data from the 140 duplex residences which were used to determine the components of normalized annual consumption. The predictive efficacy of the model was found to be very high with an adjusted R^2 of 0.93. Figures 6, 7, 8, and 9 show the plots of a multiple regression for normalized annual consumption vs. selected independent variables.

Table 5. Best subsets regression analysis for NAC using construction, occupant, and weather-related factors.

Best Subsets Regression

Using R squared as best criterion.
Model #7 R squared = 0.9313

Variable	Coef.	Std. Error	t
Constant	195169.94584	51015.0707	3.8257
Year Built	-94.47216	25.6054	-3.6895
+RC-adjusted B	429.85680	209.4373	2.0524
Cooling efficiency	683.22525	119.5730	5.7139
Heating efficiency	-500.70022	77.6834	-6.4454
Base load	352.40295	9.7978	35.9676
Tc	-221.64083	24.9964	-8.8669
Th	157.94344	23.7065	6.6625

Variable	P	VIF
Constant	0.0002	0.00
Year Built	0.0003	1.08
+RC-adjusted B	0.0421	1.02
Cooling efficiency	<0.0001	1.63
Heating efficiency	<0.0001	1.26
Base load	<0.0001	1.15
Tc	<0.0001	1.59
Th	<0.0001	1.32

Table 6. Multiple regression analysis for NAC using construction, occupant, and weather-related factors.

Multiple Linear Regression

R= 0.965 Rsqr= 0.931 Adj Rsqr= 0.928

Analysis of Variance:

	DF	SS	MS
Regression	7	2311874204.0	330267743.4
Residual	132	170506731.7	1291717.7
Total	139	2482380935.7	17858855.7

	F	P
Regression	255.7	<0.0001
Residual		
Total		

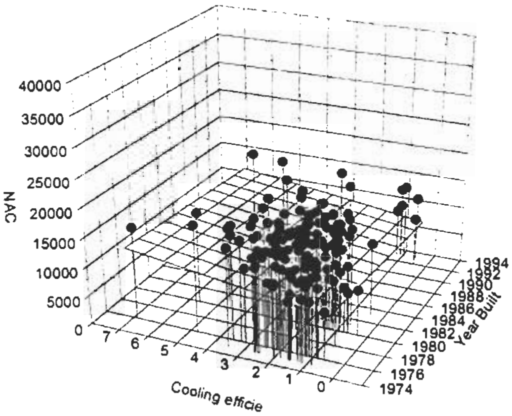

Figure 6. Plot of multiple regression for NAC vs. year built and cooling efficiency.

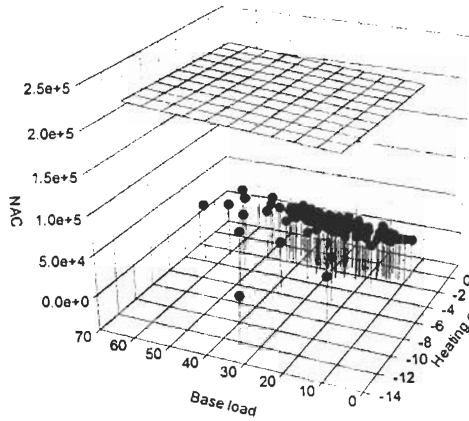

Figure 7. Plot of multiple regression for NAC vs. heating efficiency and base load.

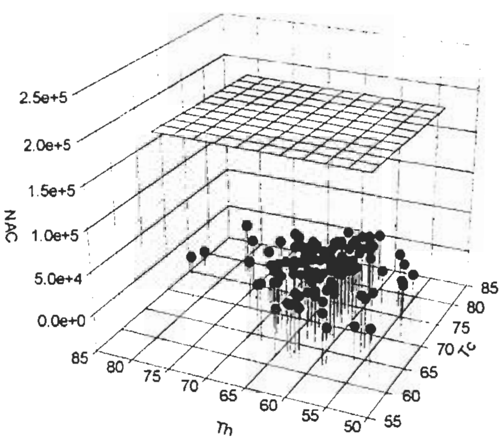

Figure 8. Plot of multiple regression for NAC vs. modified cooling balance temperature and modified heating balance temperature.

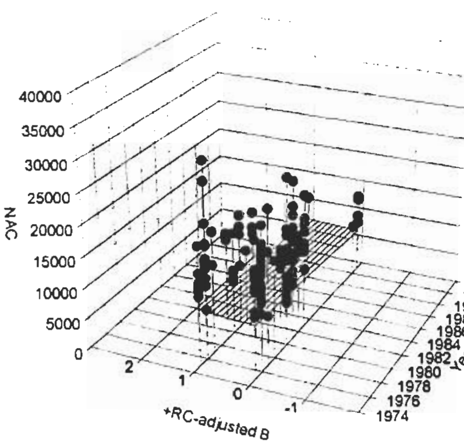

Figure 9. Plot of multiple regression for NAC vs. year built and adjust thermostat.

The negative relationship between normalized annual consumption and year built is graphed in Figure 6. This is possibly because standard building practices have improved the insulation levels and the efficiency of the mechanical equipment or that energy efficiency declines as the building and equipment age. Figures 6 and 7 show that a higher cooling efficiency and lower heating efficiency tended to have a higher normalized annual consumption. This would seem to be due to the varied ability of the structure to withstand the effects of climate related loads and varying efficiencies of heating and cooling systems within the house. A higher base load (see Figure 7) would indicate the occupants used those appliances needed for water heating, cooking, entertainment, lighting, refrigeration, and clothes washing and drying more. This behavior is usually not related to outdoor temperature. There was a negative relationship between normalized annual consumption and modified cooling balance point temperature (see Figure 8). One possible explanation for this relationship could be that a lower modified cooling balance point temperature is indicative of a lower setting of the thermostat during the cooling season. Those occupants who set the cooling thermostat lower also set the heating thermostat higher, thus causing a higher normalized annual consumption. Figure 9 shows the positive relationship between normalized annual consumption and adjusted thermostat B (adjust thermostat at bed time and in the morning). The positive relationship between normalized annual consumption and adjusted thermostat B might be explained by the lifestyle of the occupants who live in the 140 duplex residences.

SUMMARY

This study has shown that statistical models containing construction, occupant, and weather-related factors can be applied to predict dependent variable associated with energy consumption in duplex residences. The spline regression models with weather-related factors achieved adjusted R^2 values averaging 0.82. In the final regression model, construction, occupant, and weather-related factors accounted for 93% of the variance for the normalized annual consumption of 140 duplex residences. The findings showed there was a significant relationship between normalized annual consumption and year built, adjust thermostat, cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature. It was obvious that weather-related factors would be needed to analyze energy consumption. The weather-related factors such as cooling efficiency, heating efficiency, base load, modified cooling balance point temperature, and modified heating balance point temperature were not only a measure of the efficiency of the physical structure but also were values affected by occupant behavior. Being able to analyze the relationship between duplex residences and occupant behavior is the key to predicting energy consumption.

REFERENCES

ASHRAE. 1997. *Fundamentals Handbook.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Burt Hill Kosar Rittelmann Associates. 1987. *Commercial building design : Integrating climate, comfort, and cost.* New York: Van Nostrand Reinhold.

Cohen, J. 1988. *Statistical power analysis for the behavioral sciences.* Hillsdale, N J: Lawrence Erlbaum Associates Publishers.

Degelman, L. O. 1996. Personal Interview. Professor of Department of Architecture of Texas A&M University, College Station, TX.

Ellingson, L. A. 1997. *Using three-parameter models to evaluate the good cents program in College Station, Texas.* Unpublished doctoral dissertation, Texas A&M University.

Rabl, A. & Riahle, A. 1992. Energy signature model for commercial buildings: test with measured data and interpretation. *Energy and Buildings* 19: 143-154.

Gladhart, P. M. 1983. Interactions of prices and household characteristics in the determination of residential energy conservation. In B. Morrison & W. Kempton (Eds.), *Working Conference Proceedings on Families and Energy: Coping With Uncertainty* (pp. 533-550). East Lansing, MI: Michigan State University.

Fels, M. 1986. Measuring energy savings: The scorekeeping approach. *Energy and Buildings* 9.

Fox, E., Kuo, J., Tilling L., & Ulrich, C. 1994. *SigmaStat user's manual.* San Rafael, CA: Jandel Scientific Corporation.

Hankins, L. 1997. Personal Interview. Building Technician of City of College Station, College Station, TX.

Hinrichs, R. A. 1996. *Energy.* New York: Saunders College Publishing.

Jandel Corporation. 1995. SigmaStat for Windows (Version 2.0). San Rafael, CA: Jandel Scientific Corporation.

Larson, K. P. 1994. *Annual patterns and predictors of electric energy usage in occupied manufactured housing established through the use of splined, response surface, and stepwise regression techniques.* Unpublished doctoral dissertation, Texas A&M University.

LBL. 1993. DOE-2 Supplement (Version 2.1E). Berkeley, CA: Lawrence Berkeley National Laboratory.

Lechner, N. 1991. *Heating, Cooling, Lighting.* New York: John Wiley & Sons.

Roman, G. 1996. Personal Interview. Energy Auditor of City of College Station, College Station, TX.

SAS Institute. 1994. SAS System for Windows (Version 6.10). Cary, NC: SAS Institute Incorporate.

Woods, P. K. 1982. *A Statistical analysis of energy consumption in single family detached residences in Garland, Texas.* Unpublished doctoral dissertation., Texas A&M University.

Woods, P. K. 1993. Combined Energy Analysis System (Version 1.0). College Station, TX: Texas A&M University.